Fundamentals of Concrete Curing Methods in Construction Industry: A case study form theory to practice

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Abstract - *In the past few decades, advancement in concrete technology had occur in exponential curve. This leads to the use of concretes with lower water-cementitious material ratios which results into early age cracking in young concrete if special precautions are taken. In theory, concrete curing is considered as an important process in a concrete construction works, but many times in real on-site construction projects concrete curing process is often considered as low priority task or process. One of the prominent reason for this could be that the cost benefits of the good curing practices are not seen immediately, rather the consequences of poor curing will only appear in the later life of the concrete structure. The aim of this paper is to summarize the various advancements in concrete curing methods in past few decades and to review published work which evaluate the curing process in real-world concrete structures.*

Key Words: Concrete, Curing methods, Digitization, Humidity monitoring, Internet of Things, Moisture detection, Real time monitoring, Sensors, Temperature monitoring

1.INTRODUCTION

In modern era demands of concrete are increasing, while budgets are shrinking and raw materials are changing everyday. It can only be achieved through ensuring that the best strength is gained from the cementitious materials. Still it has been observed that at several sites curing of concrete is left to the decision and comfort of the unskilled labour. There is a great need to educate all stakeholders involved in a project, from the owners' board of directors to the lowest level worker, that curing process can actually be a good return value for money. It seems illogical if the cement is not allowed to hydrate for the bit of water, resulting into compromise in quality and longevity of any small or large concrete infrastructure.

The fundamental behind the need of concrete curing is very simple. Concrete undergoes a chemical process known as "cement hydration" to gain its design strength in which it requires the presence of water in the favourable range of temperatures over a defined period of time. Curing is the process of preventing the loss of moisture from the concrete whilst maintaining a satisfactory temperature regime[5]. In simple words, concrete curing is the task which encourages concrete hydration until the desired properties is obtained in the concrete. Moisture curing only influences the outer 30 to 50 mm of a concrete element's surface, and that is a critical element[11]. This explains that moisture control isn't primarily used to improve a structure's strength development, but it has a huge influence on the surface permeability and hardness, therefore it restricts a structure's design properties, particularly in extreme conditions. This is associated with an increasing adoption of concretes with water–cement ratios below 0.4, which may be more vulnerable to self-desiccation. Although external water is necessary in order to obtain the maximum benefit of such a concrete at the surface, this would not serve more than 30 mm below the surface. Internal curing techniques might be examined in this scenario.

Another positive trend is that the use of supplementary cementitious materials (SCMs), which hydrate more slowly and over an extended periods of time. A well-hydrated SCM combination will therefore provide substantially greater potential long-term durability, but an SCM combination that has already been exposed to air hastily will likely be much worse than an identically treated plain cement concrete. Another important factor is that curing requires work to regulate the temperature of the concrete. Structures or slabs which were too cold during the initial several hours following deployment will only hydrate slowly, if that were even. This may create a need of leaving forms in place for extended periods of time or adopting preventive devices to minimise plastic shrinkage cracking in a concrete. When the concrete structure is allowed to get excessively hot in the first few hours of hydration process, it is more liable to cracks depending on the temperature differences between the internal core temperature and surface temperature. Concrete which hydrates under higher temperatures seems to be more vulnerable to harmful chemical reactions and external chemical reagent attack.

While it is recognised that curing is an important co-factor, it does come at a cost and may cause delays in the construction timeline. It is also believed that a lack of curing has no measurable impact on the concrete's quality or the pay variables associated with any of it. When expenses and schedules are restricted, it's easy to underestimate the significance of curing. Concrete mixtures might be less flexible than in the past due to the greater demands placed on them. As a result, any activity that improves hydration and thus performance while lowering the chance of cracking is more significant than it has ever been. Finally, it's important to check whether the concrete curing process went smoothly or not. Direct methods, such as calculating the volume of curing compound per unit area, are easy to track, but they completely disregard regional differences, wind liabilities, or even if the job was finished within time limits. If methods other than curing substances are being adopted, the concern of how long they must be used arises. Although performance-based solutions to answering these issues have some appeal, they are often costly and inefficient. Payments are also considered a matter of assessment. Many agreements do have a part of the specifications that makes curing a pay element, but without precise assessment, it's hard to determine when payment is due, and the cash value associated to it is eventually impact worse than the potential damage to the building if it's ignored or performed inadequately. Curing is a great idea in theory, but in actuality, we must balance the system's implementation and achievement with both the effort and cost required to get there.

2. SCENARIO OF CONCRETE CURING IN REAL WORLD

2.1 Hot Climate

Alsayed et al. (1994) presented research on the impact of desert-style curing upon normal concrete. One set was sprayed twice per day every day, another was burlap-wrapped and sprayed twice per day, a third was enclosed by plastic, and the last was left to the environment. The samples were subsequently exposed to an arid climate for a year. The results along with some of the observations provided in this paper reveal that the extent of the influence of curing on sample strength is influenced significantly by sample size, with higher effects shown in smaller samples. The dryer sets' high early strengths may not be surprising, as a sample examined dry would often have greater strengths versus equivalent, wetted samples. The results show that the plastic sheets provided little moisture protection. The fact that perhaps the specimen covered in plastic had poor absorption results supports this argument. It brings up the question about whether the plastic was effectively enclosed all around specimens to minimize water evaporation, given self-desiccation is unlikely at a w/c 0.45, and other research has demonstrated the advantages of efficient plastic wrap. Another possibility is that the time span across which it was used was insufficient. The weather during the test period is not described in detail in the research, but the huge expansions that began around four months are greater than the actual shrinking. This unusual pattern can only really be explained by the variation in temperature and relative humidity status, which are most likely due to seasonal changes. The results will be useful in that those who show how important it is to consider all of the aspects that can effect a mixture's performance, and then how such performance has been measured.[2]

Hoppe et al. (1994) examines the accuracy of durability index tries in South Africa when it is used to determine the efficiency of onsite curing. All of the trial results suggest that open concrete seems to be more permeable versus concrete that has been kept moistened all of the time. The curing component was only slightly beneficial in summer-placed concrete, and, unexpectedly, performed worse in moderate-weather placements than exposed surfaces. A delayed spraying of the compound is thought to have caused solid concrete to harden sufficiently before even being treated. Later rainfall in the mild weather helped to hydrate the treated surfaces while keeping them dry. Improper application of curing chemicals, such as prolonging implementation, tends to have resulted in minimal benefit, soon as the weather is mild. A lack of proper curing resulted in a significant reduction in the system's maximum durability.[7]

With attempt to optimize specifications, **Al-Gahtani (2010)** aimed to assess the influence of curing procedures on concrete qualities. The goal of curing is to keep the concrete moist enough to allow hydration of the cement and supplementary cementitious material (SCM). In hot, dry areas, this seems to be challenging to do. Curing has a greater impact on permeability than it does on strength. For all of the cementitious systems evaluated, providing protection with curing substances appeared to be more effective than using burlap through aspects of shrinkage, strength gain, and pulse velocity. Similarly, drying shrinkage was greatest in burlap specimens and minimum in acrylic curing compound samples, while the differences were minor. The acrylic cured samples had the highest concrete strength and ultrasonic pulse velocity, while the burlap samples had the lowest.[1]

2.2 Cold Climate

The influence of SCMs, dose, and cure on scaling performance was explored by **Boyd and Hooton (2007).** The study's main goal was to link test methods and procedures to field performance, however it did show that using a curing chemical improves scaling resistance. Scaling resistance was found to be reduced when SCM content was increased in laboratory studies. There was no evidence of a link between finishing time and scaling resistance. Apparently varying curing of the laboratory-tested samples showed a consistent trend. These samples treated using curing solution had superior scaling resistance than those coated with burlap and plastic. Only the fifty percent slag mixture, which was subjected throughout the field for ten years and 600 freeze–thaw cycles, displayed any apparent and modest scaling, which was limited to the parts never cured with curing agent. Fly ash looked to boost surface strength, but slag appeared to decrease it. Finishing variations had a minor impact, whereas curing had a greater impact. The samples cured using curing compound once again produced the greatest results. It was highlighted that laying a slab well ahead of its first freezing incident might be supposed to perform well than laying a slab subsequent to the winter season.[9]

Bouzoubaa et al. (2011) investigated the impact of curing regimes on salt scaling of pavement combinations in the field and in the lab. The fly ash and compound combinations performed poorly, and they were more susceptible to maturity and curing compared to conventional concrete. Despite the fact that the research suggests that using SCMs improves prospective durability, this is not the case. These observations are most likely the product of a complex of the following variables. Scaling resistance is most likely regulated by the degree of hydration in the system, with considerable benefits achieved from tiny hydration increments, particularly in some more developed systems. Such changes seem unlikely to impact influence on performance. SCM-containing solutions are known to take longer to hydrate. This indicates that two days of burlap are unlikely to be enough to produce the moisture levels in the upper layers required for scaling resistance. In terms of the level of saturation just at exterior as well as the possibility of cracking after rapid drying whenever the burlap is peeled, curing compounds are anticipated to offer equal curing substantially higher than two days beneath burlap.[3]

2.3 High-Performance Concrete

Huo and Wong (2006) examined the dynamics of high-performance concrete (HPC) samples exposed to various curing processes at an early age. Shrinkage, temperature change, and evaporation rate were all measured. Both relative drying & shrinkage effects of such typical curing techniques were demonstrated in this study. The need of early protection for roughly seven days was emphasized once again.[8]

Poursaee and Hansson (2010) wanted to see if increasing curing time from 3 to 7 days was useful or necessary. For 100 weeks, samples were monitored for internal strain, moisture content, and temperature. The strain rose over time in all prisms, with the control combination having lower strains and the slag and fly ash combinations having little difference. There was no evident pattern in the influence of wet curing period on internal strain, according to the data. The results of this study are unexpected, and the reasons for the lack of a pattern over curing period cannot be justified based on the evidence supplied.[14]

Zhimin and Junzhe (2011) explored the role of steam curing with binder species on concrete strength properties at various depths. Many of the outcomes are in line with previous research, while others are surprising. The ternary mixture's poor performance in relation to the OPC system does not match the given data. It's likely that perhaps the chemical of the concrete mixture ingredients made them unsuitable for combining in the proportions chosen. This adverse consequence of steam on the outermost layer, on the other hand, is consistent with previous experience. Steam cure had a deleterious effect at all depths studied, according to unpublished research by the author. This has been explained as a result of faster hydration, which resulted in a coarser, more porous micro-structure.[6]

2.4 Performance Parameters

Petrou et al. (2001) looked at bridge deck cracking. Improper curing was indeed a main cause to cracking in 4 of the decks studied, according to the study. In addition, structural deflections must be balanced by mixture stiffness, along with structural strength, permeability, & cracking risk. The discussion of the impact of slump upon cracking risk must be handled with caution. The paste–water proportion of a solution has a direct influence on shrinkage. There existed a connection among slump and cracking when slump was predominantly regulated by water content in a combination, however this link is no longer valid in today's technology, when slump is regulated by mix proportions.[12]

In South Dakota, **Johnston and Surdahl (2007)** explored the relationship between a number of parameters that affect cracking within continuously reinforced concrete (CRC) pavement. The findings back with the theory that a variety of conditions can increase the chance of cracking. Although some parameters, such as temperature, have a great impact, they are difficult to manage; hence, modifying the somewhat smaller variables that can be modified, including such accelerated curing, could still have a significant impact.[10]

To track curing, **Radlinski et al. (2008)** employed maturity measures. Maturity is a method for predicting a concrete's compressive strength depending on the product of temperature and duration undergone by a mixture. One of the goals of the study was to see if the methodology could be used to monitor mixes with added cementitious ingredients. The heat profile's lack of sensitivity towards curing is remarkable. The authors attribute this to the availability of water in the system, yet more extra water for hydration might result in a higher hydration heat. The specimen that is permitted to be evaluated dry, from the other side, is predicted to have better instead of lesser strengths. It's possible that the effect exists but is less than the data collecting precision. The consequences of intermittent wetness should be carefully considered. The study relied on compression strength measurements on 150 mm cylinders. Examination of porosity at the faces of such various samples would almost certainly have resulted in a different outcome. The results indicate the impact of curing technique mostly on long-period hydration of a cementitious material once again.[15]

Bouzouba et al. (2010) analysed the effect of mixture parameters on carbonation processes in both laboratory and field testing. Curing for longer than three days appears to provide little benefit in terms of carbonation. It's also worth noting that carbonation in higher-grade concrete mixtures was less affected by fly ash levels.[4]

Peyton et al. (2012) likewise looked into bridge deck cracking. In 2005, five under-construction bridge decks were evaluated to see which of these conditions contributed to cracking: Structural design, material qualities, proportioning of mixtures, construction methods, and curing methods Despite the fact that all of the bridges were treated using both curing chemical & moist burlap and plastic, considerable cracking was noted, particularly in those where curing began late. This underlines the importance of properly timing curing to get the best benefit.[13]

The goal of **Tamayo's (2012)** research was to see if lithium silicate additives raises the risk on plastic shrinkage cracking across 4 Arkansas bridge decks. A portion of every floor had been sprayed using lithium silicate like a completing aid, while the rest was treated with standard curing chemical. Although the lithium silicate was employed to reduce cracking rather than as a curing agent, this claims to also be productive and cost-efficient.[16]

3. CONCLUSION

Concrete curing is vital for constructions which have been subjected to harsh conditions, particularly in terms of ultimate durability. In dry regions, self-desiccating combinations must be avoided because supplementary water techniques may indeed be hard to implement. The probable durability of a concrete structure can be drastically decreased if curing treatments are applied late. Some studies found that curing compounds performed much better, while many others claimed burlap and plastic to be preferable. If curing substances are placed before bleeding has stopped, effectiveness is likely to suffer. Curing chemicals tend can provide protection comparable to moist curing for 3 to 7 days. Curing is necessary for the most quality parameters over 3 to 7 days, with extended duration required for concrete containing Supplementary cementitious materials. Although steam curing can increase its strength, it can also reduce durability. The possibility of cracks can indeed be reduced with proper curing. Lithium silicate compounds tend to be beneficial in preventing bridge deck damage. Optimizing and regulating the pace of the curing appears to improve curing effectiveness.

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